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THE WATER FACTOR IN HARVEST-SPROUTING OF HARD RED SPRING WHEAT

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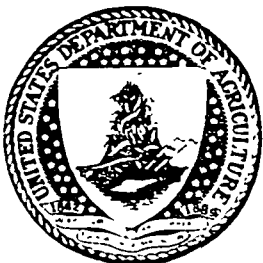
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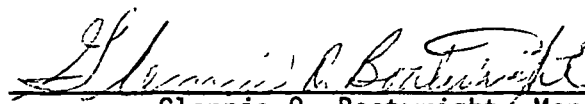
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THE WATER FACTOR IN HARVEST-SPROUTING
OF HARD RED SPRING WHEAT

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THE WATER FACTOR IN F "GERMINATING OF HARD RED SPRING WHEAT^{1/}

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Armand Bauer and A. L. Black^{2/}

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THE WATER FACTOR IN HARVEST-SPROUTING OF HARD RED SPRING WHEAT

Armand Bauer and A. L. Black

ABSTRACT

Sprouting in unthreshed, ripe, hard red spring wheat (Triticum aestivum L.) is induced by rain, but sprouting does not necessarily occur because the crop is wetted. The spike and grain water conditions conducive to sprouting were determined in a series of laboratory experiments.

Spike water concentration increased linearly by one percentage unit/min, oven-dry spike weight basis, when continuously misted at 1.9 cm/hr rate. Water loss from spikes dried 12 hrs at 80% relative humidity immediately after wetting to 105% water concentration was 2 percentage units/hr faster than the loss from spikes equilibrated 21.5 hrs after wetting to the same concentration; at 35% relative humidity the difference after equilibration was 1.7 percentage units/hr less. Spikes equilibrated at 55 to 105% water concentration lost about 2.5 percentage units/hr drying 8 hrs at 80% relative humidity; at 60 and 35% relative humidity loss rate was 5 and 7 percentage units/hr, respectively, at 105% spike water concentration, declining to 3 percentage units/hr at 55% spike water concentration.

Water imbibition rate of grain increased as spike water concentration increased from 15 to 145%, and decreased with increase in equilibration time. Maximum imbibition was 1.7 percentage units/hr at 145% spike water concentration after 15 hrs equilibration.

Based on the coleoptile being visible, the minimum equilibrated threshold spike water concentration to effect sprouting is 45-49%.

Coleoptiles emerged sooner in spikes equilibrated to water concentrations $> 49\%$. Sprouting did not occur in field-growing wheat wetted to 110% water concentration until the spike water concentration was reduced to 12% and maintained at this concentration for 2 days before wetting. When cut at growth stage 11.3, Feekes scale, Saratovskaya 29 (USSR) sprouted after 4 days drying, Olaf and Alex between 7 and 15 days drying and Columbus, recognized for its resistance to harvest-time sprouting, after more than 15 days drying. Sprouting potential was enhanced after 4 wetting-drying cycles in which any wetted interval was too brief to permit sufficient water imbibition to initiate sprouting. At harvest ripeness, grain water concentration exceeded spike water concentration by 0.7 percentage units.

Following 6 months storage, 20% of the kernels in 300-spike bundles (simulating windrows) sprouted within 28 hrs after initiation of wetting to saturation (150% water concentration). Ninety percent sprouting occurred within 8 days in bundles maintained at 75% water concentration and higher, but less sprouting occurred in bundles dried to 50% water concentration before re-saturation.

Additional index words: dormancy, primary dehydration of wheat, misting, water imbibition rate, spike wetting rate, spike drying rate, threshold spike water concentration.

INTRODUCTION

Sprouting of harvest-ready wheat results in a degradation of grain proteins and starches, and therefore in a reduction in flour quality (Gordon et al., 1977), grain grade and marketability, and net return to the producer. Sprouting occurs most frequently in soft white wheats (Ciha, 1981). Sprouting in hard red spring wheat (Triticum aestivum L.) grown in the United States is considered to occur only sporadically, yet 12% of this crop and 19% of the durum (Triticum durum Desf.) produced in North Dakota in 1977 had detectable sprout damage (Briggle, 1980). Damage also was sustained by the 1980 crop. Breeding programs are developing sprout-resistance in hard red spring wheat (Campbell and Czarnecki, 1981) as well as in other wheat classes.

Sprouting is rain-induced, but it does not necessarily occur when a crop is wetted by rain (Wellington and Durham, 1958). Enough water must be imbibed by the grain (Derera, 1980) to synthesize or activate the necessary enzymes (Gordon et al., 1977) to initiate germination. The minimum grain water concentration required by wheat for this process is in the range of 35 to 40% (Peterson, 1965).

Spike water absorption rate exceeds the water imbibition rate of grain (Gordon et al., 1977). On a dry basis, spike water concentration of an Australian white wheat increased linearly at about 11.5 percentage units/hr the first 10 hours, about 3 percentage units/hr the second 10 hours. Grain water concentration increased linearly at about 1.9 percentage units/hr over the range of 14% to 100%. Grain water imbibition rate of 10 soft white winter wheats was

4 to 5 percentage units/hr over a 10-hour period, from an initial 10% water concentration (Ching and Foote, 1961).

Freshly harvested winter wheat seeds typically require a maturation or after-ripening period before germination can occur (George, 1967). Ten soft white winter wheats required 3.4 to 8.4 days to produce 50% germination when incubated at 20 C 4 days after cutting (Ching and Foote, 1961). Seed dormancy conferring sprout resistance is recognized also in hard red spring wheat (Noll et al., 1982). Sprouting of the mature hard red spring wheats Neepawa, Columbus, and RL 4137, 5 to 7 days after cutting was 42, 11, and 4%, respectively, (Noll and Czarnecki, 1980).

Seed dormancy is not the only factor responsible for sprout resistance. Plant factors which also contribute are endosperm sensitivity to gibberellins, potential of the caryopsis to synthesize hydrolytic enzymes, especially alpha-amylase, fiber content, permeability of the pericarp to water and oxygen, embryo response to inhibitors, and presence of germination inhibitors in the bracts (Derera et al., 1977).

In North America, hard red spring wheat is grown primarily in the semiarid and subhumid northern plains of the United States (Reitz, 1976) and the Canadian prairie provinces. Either of two methods is used to harvest. In straight (direct) combining, the crop is simultaneously cut and threshed; and in the swath-combine method the crop is swathed into windrows, and after drying to the desired water concentration, picked up with attachments to the combine and threshed.

With interest growing in forecasting crop production over large areas (Doraiswamy and Thompson, 1982), information is needed for model development to provide predictive capability of the effect of episodal events at harvest on crop production. Such information is lacking in general and absent for hard red spring wheats. Models to predict potential sprouting problems in soft white wheats have been developed for the Netherlands (Belderok and Habekotte, 1980).

These experiments were conducted to alleviate the paucity of information defining the role of the water factor in harvest sprouting of hard red spring wheat.

MATERIALS AND METHODS

The experiments in the laboratory were conducted over the four-year period, 1979 to 1982. Hard red spring wheat samples were obtained from farm fields and research plots.

Two methods of misting were used to wet the samples. In all experiments except #3, misting nozzles of the type used by plant pathologists to create a moist environment were positioned about 0.5 m above the samples and misting was continuous over the desired time interval. During misting, the samples of grain spikes or grain bundles were in a horizontal position. To establish precise water concentrations, small quantities of water were applied with an atomizer after the misting procedure. In experiment #3, all water was misted with an atomizer.

Gain or loss of water by the samples was determined by weighing before and after misting, and before and after oven-drying at 69 C. Water concentration is expressed on a dry weight basis.

An emerged coleoptile was the measure of sprouting. Each kernel was individually examined under magnification. All examinations were made by the same individual. Degree of visible sprouting is the criterion used in grading wheat in the United States for this malady (Briggle, 1980). But sprouting and alpha-amylase production associated with it can occur before damage can be visually determined. Plant breeders use several selection criteria to assess sprouting, but particularly they use the visible coleoptile (Gordon et al., 1977).

Commercial type environmental-control chambers were used for the equilibration/incubation procedures in experiments #3 through #7. The chamber used for environmental control in experiment #9, housed in a room, is described by Krupinsky and Scharen (1983). Access was provided through a 0.5 m^2 opening in one end, and about 5 cm of soil was placed at the bottom of each chamber which was wetted to and maintained at 0.033 MPa tension. A screen was placed about 3 cm above the soil to support the bundle samples. Constant environmental conditions were maintained with electronically controlled thermostats, humidifiers, and dehumidifiers.

Statistical analysis procedures followed those of LeClerc et al. (1962), in consultation with a statistician. Computer programs utilized for regression and analysis of variance are described in SAS 76 (Barr et al., 1976).

Experiment #1 -- Spike wetting rate.

Mature Wared wheat was cut, at random, at the soil surface in August 1980 and stored in open, plastic bags at room temperature until February 1981. Then spikes were severed from stems, 12 sets of 40 spikes per set were weighed, and each set uniformly spread out, single layer, on a screen tray. One set each was misted for 0, 1, 2, 3, 4, 5, 10, 20, 25, 28, 35, and 50 minutes at a rate of 1.9 cm/hr. After being misted, the spikes were covered with a clear plastic sheet for 20 min to allow drainage of free water without evaporation. Samples were weighed to determine the water concentration.

Experiment #2 -- Wetted spike drying rate.

The source and age of the spikes were the same as in experiment #1. Eighteen sets of 40 spikes per set were uniformly spread out, single layer, on screen trays, one set per tray. Three sets were misted at 0.8 cm water/hr for 0.5, 1, 3, or 7 hours, and 6 sets for 15 hours. Immediately after being misted, the 12 sets misted 7 hrs or less and 3 sets misted for 15 hrs were weighed, sealed in plastic bags, and equilibrated for 21.5 hrs in a controlled environment chamber at 24 C and 100% relative humidity. Three sets misted for 15 hrs were not equilibrated. Six sets, each representing a different treatment, were dried under a variable, controlled relative humidity of 35%, 60%, or 80% (± 5), all at 21 C in quiet air. Within each humidity regime, one set was weighed after 0, 1, 2, 4, 6 or 8, and 18 or 20 hrs of drying.

Experiment #3 -- Water imbibition rate of wheat grain.

Mature Olaf wheat was cut, at random, at the soil surface in August 1981 and stored in open plastic bags at room temperature until December 1982 when spikes were severed from the stem. Twenty spikes were oven-dried to determine the initial water concentration. Sets of 20 spikes were placed in plastic bags and misted to variable water concentration of either 15, 40, 75, 110, or 145% with an atomizer. After being misted, the plastic bags were sealed and placed into a controlled environment chamber at 20 C and 100% relative humidity for either 15, 24, 48, 73 and 98 hrs. Each treatment of water concentration and equilibration time was repeated twice. After equilibration, the grain was separated by hand from the chaff from all spikes in the set, weighed, oven-dried and re-weighed. Data were

statistically analyzed as a factorial with fixed variables.

Experiment #4 -- Equilibrated threshold spike water concentration effecting sprouting.

The source and age of spikes were the same as in experiment #1. Forty-two sets of 40 spikes per set were uniformly spread out, single layer, on screen trays, one set per tray. Six sets each were misted to average spike water concentrations of <14, 25, 38, 43, 49, 50, and >65% by weight. After being misted, each set was sealed in a separate plastic bag and placed in a controlled environment chamber for 3, 6 or 14 days at 13 C or 24 C, and 100% relative humidity. After oven-drying, each set was threshed and each kernel was examined for sprouting. Data were statistically analyzed as a factorial with fixed variables.

Experiment #5 -- Effect of water concentration during primary dehydration on sprouting.

Spikes were cut at random from field-growing Olaf, Alex, and Saratovskaya 29 (USSR cultivar) on 4 dates in 1982 when spike water concentrations averaged 42, 22, 17, and 12%. Forty spikes per set as taken from the field were misted to 110% water concentration, sealed in plastic bags, and placed in a controlled environment chamber for either 3 or 6 days at 13 C and 100% relative humidity. A companion set of 40 spikes per set, cut on the same day and at the same water concentration, was air-dried at 20-25 C to about 12% water concentration. Two days after this water concentration was attained, the spikes were misted to 110% water concentration and placed in the environmental chambers. After being removed from the chamber, the

sets were oven-dried, weighed, and threshed. Each kernel was examined for sprouting. Data were analyzed as a factorial with fixed variables.

Experiment #6 -- Cultivar differences in sprouting after primary dehydration.

Samples of Alex, Columbus, Olaf, and Saratovskaya 29 (USSR cultivar) were cut at random at the soil surface at growth stage 11.3, Feekes scale (Large, 1954), in August 1981, when the spike water concentration averaged 14.5%, and stored at room temperature. Spikes were severed from the stems on day 4, 7, 11, 15, and 30 after cutting, then sets of 20 spikes were misted to water concentrations of either 45, 70, or 90% (± 3) by weight. After being misted and weighed, each set was sealed in a separate plastic bag and placed in a controlled environment chamber for either 3, 6, or 14 days, and at either 13 C or 24 C, at 100% relative humidity. Each treatment was repeated twice. After the spikes were threshed, each kernel of each set was examined for sprouting. Data were analyzed as a factorial with fixed variables.

Experiment #7 -- Wetting-drying cycle effects on sprouting.

Olaf wheat at Feekes growth stage 11.3, was cut at random at the soil surface in August 1981 and stored in open, plastic bags at room temperature until February 1982. Spikes were severed from stems and 20 spikes per set were misted to bring the water concentration to variable levels of 49%, 66%, and 80% (± 5), oven-dry basis. After being misted, each set of 20 spikes was sealed in a plastic bag for 6 hrs. The bags then were opened and placed in a controlled environment chamber with circulating air at 24 C and 20% relative

humidity for 16 hrs. During this 16-hr period spike water concentration was reduced to about 15%. Wetting-drying cycles were imposed by re-misting either 0, 1, 2, or 4 times followed by the described drying procedure. Immediately after being misted the last time, each set was sealed in a plastic bag and equilibrated for either 2, 4, or 7 days in a controlled environment chamber at 13 C and 100% relative humidity. Each treatment was repeated twice. The spikes were threshed and each kernel of each set was examined for sprouting. Data were analyzed as a factorial with fixed variables.

Experiment #8 -- Water concentration of the spike, grain, and chaff during primary dehydration.

Two sets of 12 spikes of Sinton wheat were removed at random from field-growing Sinton wheat from 4 replications on 6 dates (8/18, 8/22, 8/25, 9/01, 9/02, and 9/07, 1982). Spike water concentration was determined on one set at each date. The grain was removed from each spike of the second set, and the grain and vegetative parts (chaff) were weighed and dried separately to determine the water concentration. The data were analyzed as a randomized complete block.

Experiment #9 -- Sprouting in bundles (simulated windrows).

A. One wetting

Bundles of 300 spikes were made up of Wared wheat, cut at random at the soil surface in August 1980 and stored in open plastic bags at room temperature for 6 months. Six bundles, placed on screen trays, were misted at 0.8 cm water/hr for 16 hours on 25 February 1981 to a water concentration of about 150%, oven-dry basis. After being misted, 4 of the 6 bundles were placed in a daytime controlled environment of 23 C and 85% relative humidity, and a nighttime

environment of 7 C and 100% relative humidity; one each was in the chamber 2, 4, 8, and 15 days. The other 2 bundles, after being misted, were in a chamber for 12 hours at 23 C -- one at 100% relative humidity and the other at 25-30%. At termination, each bundle was oven-dried, weighed, and threshed. Six hundred kernels from each bundle were randomly removed from the bulk pool in lots of 100 kernels, and examined under magnification for sprouting.

B. Wetting and re-wetting

Fourteen bundles were misted at the same rate and to the same water concentration as in part A. After being misted, the bundles were placed into a controlled environment chamber with daytime environment of 23 C and 50% relative humidity, and nighttime at 7 C and 100% relative humidity. Five of the 14 bundles were misted once, and one each of these was oven-dried 1, 2, 3, 5, and 11 days after being misted. Five other bundles were re-misted when the water concentration decreased to about 110%; one each of these was re-misted 1, 2, 3, 4, and 5 times with a 2- or 3-day interval between mistings. These bundles were oven-dried one day after the last misting. The remaining 4 bundles were re-misted after the bundle water concentration decreased to about 75%; one of these 4 was re-misted once, and the other 3 bundles each 3 times. These 4 bundles were oven-dried 3 days after the last misting. At termination, each bundle was oven-dried, weighed, and threshed. Six hundred kernels from each bundle, randomly removed from the bulk pool in lots of 100 kernels, were examined under magnification for sprouting.

RESULTS AND DISCUSSION

Spike wetting rate

Spike water concentration in Wared wheat increased linearly at about 1 percentage unit/min, oven-dry spike weight basis, over a 50-min period when continuously misted at a rate of 1.9 cm/hr (Fig. 1). This absorption rate is about 5 times faster than reported by Gordon et al. (1977) in Australian white wheat misted 10 min at commencement of wetting and 5 min of each hr thereafter. At an absorption rate of 1 percentage unit/min, spike water concentration could increase from 10% to 150% from a rain of 2.3 hrs duration. The 1.6 cm water misted in 50 min was equivalent to at least 17 times more water than the actual amount needed to increase the water concentration from 10% to 150% in 4000 kg of spikes/ha.

The initial water absorption rate is likely not the same among spikes of the same or different cultivars. Those with "loosely" packed spikelets initially may absorb water more rapidly than the spikes with "densely" packed spikelets because of the larger volume of interstitial space provided for adsorption.

Wetted spike drying rate

Water loss from spikes wetted to 105% water concentration was more rapid when drying was initiated immediately after misting than if initiated after 21.5 hrs equilibration (Fig. 2). During equilibration, water was imbibed by the grain from spike non-grain parts. Hence, the drying rate of the equilibrated spikes was determined in part by the water transmission properties of the grain. In contrast, the water absorbed by non-equilibrated spikes

was being held in non-grain parts and the interstitial spaces among and within the spikelets. This condition presented less of a barrier to evaporation than water absorbed into the grain.

Climatic conditions which depress evaporation after a rain enhance the sprouting potential because of the time provided for water imbibition by the grain. Spike vegetative parts and interstitial spaces act as a water reservoir for imbibition. The non-grain parts of mature spike (glumes, rachis, etc.) comprise about 28% of its oven-dry weight^{1/}. At 150% water concentration, the non-grain spike parts per se hold enough water to increase grain water concentration 42 percentage units if all of the water held is imbibed by the grain. Only absorptive forces of the dead inflorescence tissue would reduce the amount of water available for imbibition (Gordon et al., 1977).

Water loss from spikes equilibrated between 55 to 105% water concentration was slightly more than 2 percentage units/hr over the initial 8 hrs drying time in an environment of 80% relative humidity and 21 C (Fig. 3). At 60 and 35% relative humidity, the loss was about 5 and 7 percentage units/hr, respectively, from equilibrated spikes at 105% water concentration, but about 3 percentage units/hr from those equilibrated to 55%. At 80% relative humidity, the loss rate was governed essentially by the evaporative demand of the atmosphere, but at lower humidities and in association with spike

^{1/} Unpublished data. This value is an average of 77 observations over a 3-year period.

water concentrations less than about 75%, water transmitting properties of the grain became a rate limiting factor.

Grain water imbibition rate

Grain water imbibition rate by Olaf wheat varied with spike water concentration and equilibration time (Table 1). The initial grain water concentration of 20 spikes was 9.7%. Imbibition rate/hr increased with increase in spike water concentration (Fig. 4) and decreased with time. Maximum imbibition was 1.7 percentage units/hr at 145% spike water concentration after 15 hrs equilibration.

Except at a 15% spike water concentration, imbibition was in a curvilinear mode, as determined from stepwise regression. This is in contrast to the linearity exhibited by Australian white wheat (Gordon et al., 1977). The difference may be due to the more vitreous characteristics of hard red spring wheat. Also, Gordon et al. (1977) misted 10 min the first hr and 5 min every hour thereafter, in the interim maintaining the spikes in a high humidity environment. Furthermore in their study, only the first and second kernels (grains) of each spikelet in the central two-thirds of the spike were used to minimize potential differences in grain growth and development within the spike. In our experiment, the water was imbibed from once-wetted spikes.

Equilibrated threshold spike water concentration effecting sprouting

The equilibrated threshold spike water concentration initiating sprouting is about 45-49% (Table 2). Significant sprouting occurred in Wared wheat equilibrated for more than 6 but less than 14 days after misting. Spikes equilibrated at 60% water concentration or higher had significant sprouting in less than 6 days after misting.

At a water imbibition rate of 1.5% percentage units/hr, wheat grain at harvest ripeness, 12.5% water concentration (Gordon et al., 1979), will require about 24 hrs to imbibe sufficient water to initiate sprouting.

Temperature during equilibration had no effect on sprouting (data not shown).

Effect of drying field-growing wheat on sprouting

Spikes removed from the field at water concentrations ranging from 42 to 12% during primary dehydration had significantly more sprouting when they were air-dried and maintained at about 12% water concentration for two days before wetting to 110% water concentration than those that were not dried prior to wetting. (Drying x spike water concentration interaction was not significant). These data (Table 3) imply that the sprouting mechanism is not triggered or the dormancy factor is not overcome until the grain water concentration during primary dehydration is reduced to about harvest ripeness. Darryl Smika, USDA-ARS, Akron, CO and local wheat growers (personal communications) have observed that grain in spikes wetted during primary dehydration before it is harvest ripe will not sprout but instead will mildew.

Differences existed among cultivars, as indicated by the significantly higher sprouting in Saratovskaya 29 than either Alex or Olaf.

Cultivar differences in sprouting

The time required after cutting at Feekes growth stage 11.3 (Large, 1954) to become susceptible to sprouting differed among

cultivars (Table 4). Significant sprouting occurred in Saratovskaya 29 after 4 days drying, in Olaf within 7 days, in Alex within 15 days, and in Columbus within 30 days. Significant sprouting of Olaf equilibrated at 45% water concentration suggests that the threshold spike water concentration initiating sprouting may differ among cultivars in view of the results obtained with Wared wheat (Table 2). As with freshly harvested winter wheat (George, 1967), hard red spring wheats require a maturation or after-ripening before germination can occur. The outstanding attribute of Columbus is its resistance to harvest-time sprouting, reflected in its low alpha-amylase concentration (Campbell and Czarnecki, 1981).

Sprouting averaged 9.2% at 13C and 2.7% at 24C, significant at the 5% level. Sprouting increased with days of equilibration (incubation). After 3 days, average sprouting was 3.3%, after 6 days 5.4%, and after 14 days 9.1%, significant at the 5% level. (LSD for days equilibration was 1.2% sprouting).

Effect of wetting-drying cycles

Sprouting potential is enhanced by wetting-drying cycles in which the wetted interval is too brief to permit grain to imbibe sufficient water to effect germination (Table 5). Sprouting in Olaf wheat was significantly increased with the fourth wet cycle. Suggested reasons for enhancement are that wetting irreversibly alters the grain water transmitting properties in the direction of an increase in subsequent imbibition rates, and/or that some water is retained within the grain from each wetting which then reduces the quantity needed from subsequent wettings to effect germination. The penetration depth of wetting into the grain was not determined. Significantly more

sprouting occurred when the spike water concentration in the wet phase was brought to 80% than when it was brought to 49% (Table 5).

Spike, grain, and chaff water concentration during primary dehydration

Grain water concentration was consistently higher than the spike water concentration during primary dehydration (Table 6), but the difference decreased with time. Thirteen days before harvest ripeness the difference was less than 3 percentage units, and by harvest ripeness less than 1 percentage unit. Hence at harvest ripeness, the measured spike water concentration is a measure of the grain water concentration.

The water concentration of the chaff (non-grain prt of the spike) was consistently lower than in the grain during primary dehydration (Table 6), but the difference decreased with time. By harvest ripeness the difference was about 2.5 percentage units.

Water concentration in the chaff varied more than in the grain at each sampling. Chaff water concentration changed during the day in response to relative humidity. In preliminary investigations we found the chaff water concentration was consistently higher during early morning hours than mid-afternoon.

Sprouting in bundles

Sprouting of Wared wheat in bundles simulating windrows occurred within 12 hrs after being misted for 16 hrs (Fig. 5). Sprouting after 12 hrs was 12 percentage units higher when the post-misting environment was 100% relative humidity than 25-35%. Based on regression which included all bundles maintained at or above 75%

water concentration, (shown on Fig. 5), 90% sprouting occurred within 8 days after the initial 16-hr misting period. When the regression analysis excluded the 4 bundles dried to 75% water concentration before re-misting, the resulting equation was: $Y = 16.53X - 0.81X^2 + 10.08$, where X = days after misting ($R^2 = 0.74^{**}$). This equation predicts only 4 percentage units less sprouting in 3 days than the equation which includes the 4 bundles re-misted after drying to 75% water concentration, and about 6 percentage units more after 7 days. Apparently sprouting was as extensive in bundles dried to 75% water concentration before re-misting as in those which were re-misted after they dried to 110% water concentration. But maximum sprouting in bundles dried to 50% water concentration before re-misting was 10 percentage units less than in those re-misted at 75% water concentration (data not shown). In addition to less sprouting upon drying to 50% before re-misting, maximum sprouting did not occur until the 11th day after initial misting.

SUMMARY

In addition to a water source, two conditions must be met to effect sprouting in harvest ripe hard red spring wheat. First, spike water concentration must have been reduced to harvest ripeness, about 12-14% water concentration, at least once and retained at this level for a period differing with cultivars (at least 2 days in the cultivars used), to overcome dormancy. Second, the spike must remain wet long enough for the grain to imbibe enough water to attain a 45-49% water concentration. The rate of imbibition varies with spike water concentration. The maximum measured with hard red spring wheat was about 1.7 percentage units/hr, oven-dry grain weight basis. Once dormancy is removed as a sprout-limiting factor, extent of sprouting is governed by the length of time the grain remains wetted above the sprout threshold water concentration.

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Table 1. Wheat grain water concentration reflecting the effect of spike water concentration and equilibration time on imbibition.

<u>Hours equilibrated</u>	<u>% spike water concentration</u>					<u>Average[†]</u>
	<u>15</u>	<u>40</u>	<u>75</u> % water in grain	<u>110</u>	<u>145</u>	
15	12.5 [†]	24.5	29.0	32.5	35.5	26.8
24	14.1	27.9	35.3	40.4	44.0	32.3
48	16.5	36.0	50.3	54.3	59.9	43.4
73	13.9	34.1	50.9	60.0	64.5	44.7
98	17.5	40.3	55.7	65.6	73.5	50.5
Average [§]	14.8	32.5	44.2	50.5	55.5	

† LSD (0.05) for hours equilibrated x spike water concentration = 1.0.

‡ LSD (0.05) for hours equilibrated = 0.5.

§ LSD (0.05) for spike water concentration = 0.5.

Table 2. Percent sprouting in wheat spikes after equilibration at several water concentrations for varying numbers of days at 100% relative humidity.

<u>Water concentration</u> %	<u>Days incubated</u>			<u>Avg.</u> [†]
	<u>3</u>	<u>6</u>	<u>14</u>	
	% sprouting			
<14	1 [†]	0	1	1
25	1	0	1	1
38	1	1	1	1
43	1	1	11	4
49	2	28	57	29
60	14	73	65	51
65	16	55	90	54
Avg. [§]	5	22	32	

† LSD (0.05) for water concentration x days incubated = 34% sprouting.

‡ LSD (0.05) for water concentration = 14% sprouting.

§ LSD (0.05) for days incubated = 13% sprouting.

Table 4. Percent sprouting of four wheat cultivars as affected by days after cutting and equilibrated spike water concentration.

Cultivar	Water concentration %	Days after cutting				
		4	7	11	15	30
		% sprouting				
Columbus	45	0 [†]	1	0	0	0
	70	0	1	0	1	2
	90	3	1	2	3	9
Alex	45	0	0	0	0	3
	70	1	1	3	8	21
	90	1	2	3	8	22
Olaf	45	1	3	1	2	11
	70	3	5	5	8	19
	90	3	7	7	10	28
Saratovskaya 29	45	3	1	2	2	6
	70	9	6	3	7	23
	93	7	12	13	9	44

† LSD (0.05) for cultivar x water concentration x days after cutting = 5.6% sprouting.

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Table 5. Effect of spike re-wetting frequency to three water concentrations on susceptibility to sprouting in wheat.

<u>Water concentration</u> %	<u>Times re-wetted</u>				<u>Avg.</u> [†]
	<u>0</u>	<u>1</u>	<u>2</u>	<u>4</u>	
	% sprouting				
50	5 [†]	6	9	10	7
60	8	8	11	27	14
80	13	27	22	35	25
Avg. [§]	9	14.	14	24	

[†] LSD (0.05) for water concentration x times re-wetted = 10% sprouting.

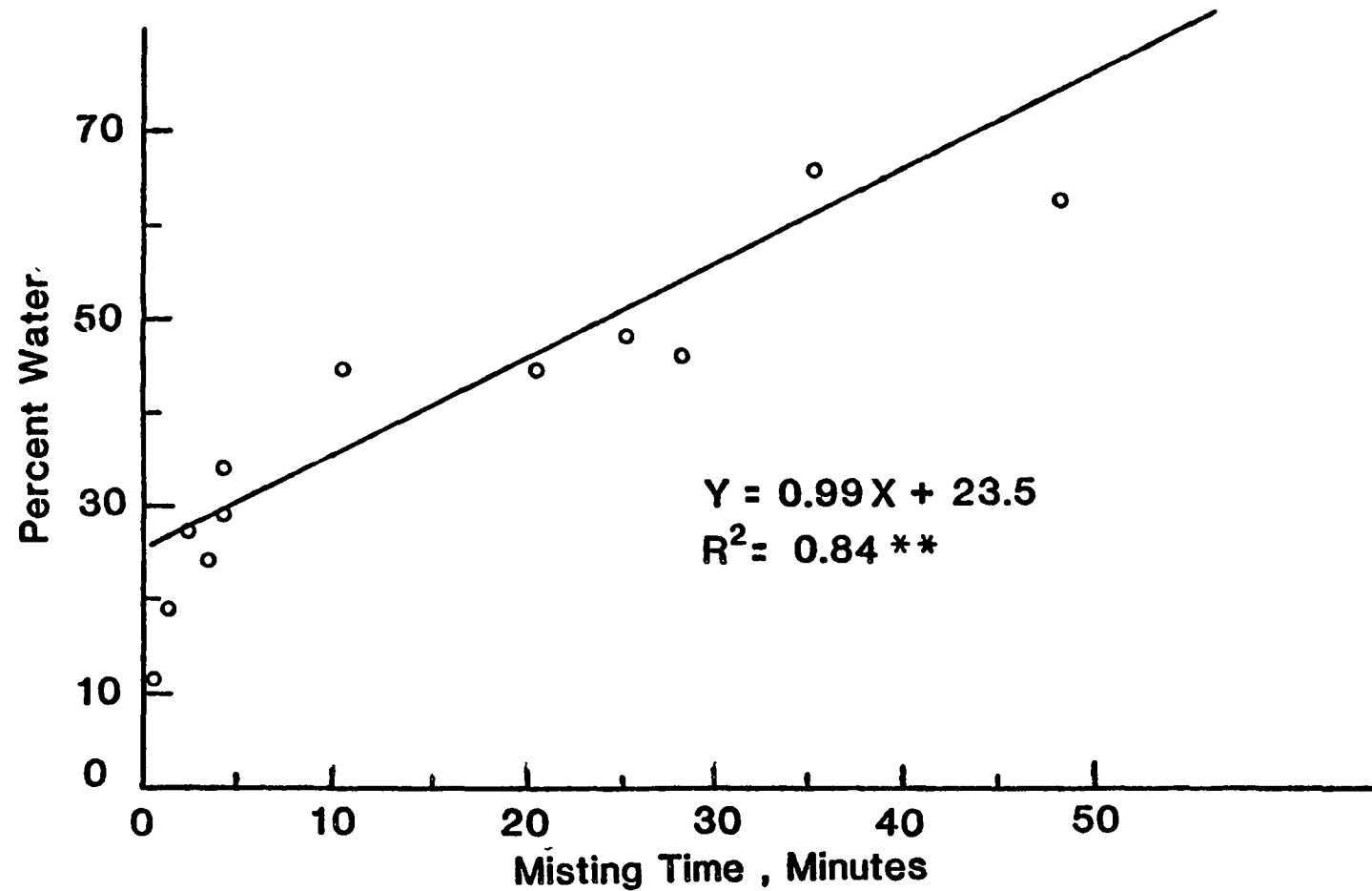
[‡] LSD (0.05) for water concentration = 5% sprouting.

[§] LSD (0.05) for times re-wetted = 6% sprouting.

Table 6. Change in water concentration in spikes, grain, and chaff during primary dehydration.

<u>Date</u> mo/day	<u>Measurement</u>		
	<u>Spike</u>	<u>Grain</u> % water	<u>Chaff</u>
8/18	69.5	82.5	44.0
8/22	46.8	53.8	30.3
8/25	27.0	29.8	20.3
9/01	24.0	26.0	18.8
9/02	18.8	19.8	15.0
9/07	11.8	12.5	10.0
LSD	6.9	5.4	12.0

Figure 1. Water Concentration , Oven-dry , of 40 Wheat Spikes
Misted at 1.9 cm/hr.



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Figure 2. Effect of 21.5 Hours Equilibration After Misting on Cumulative Water Loss From 40 Wared Wheat Spikes Dried at 35% and 80% Relative Humidity.

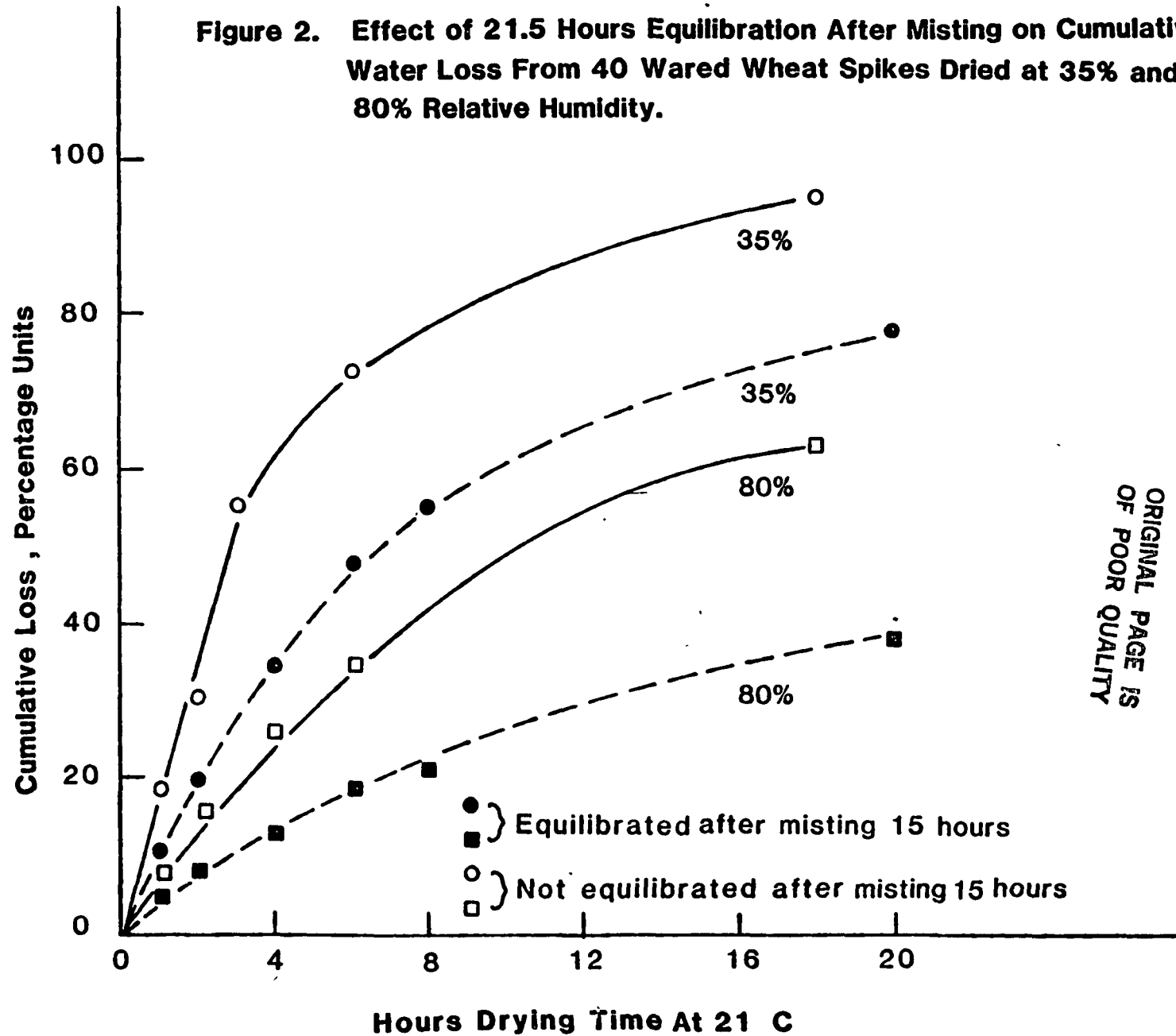
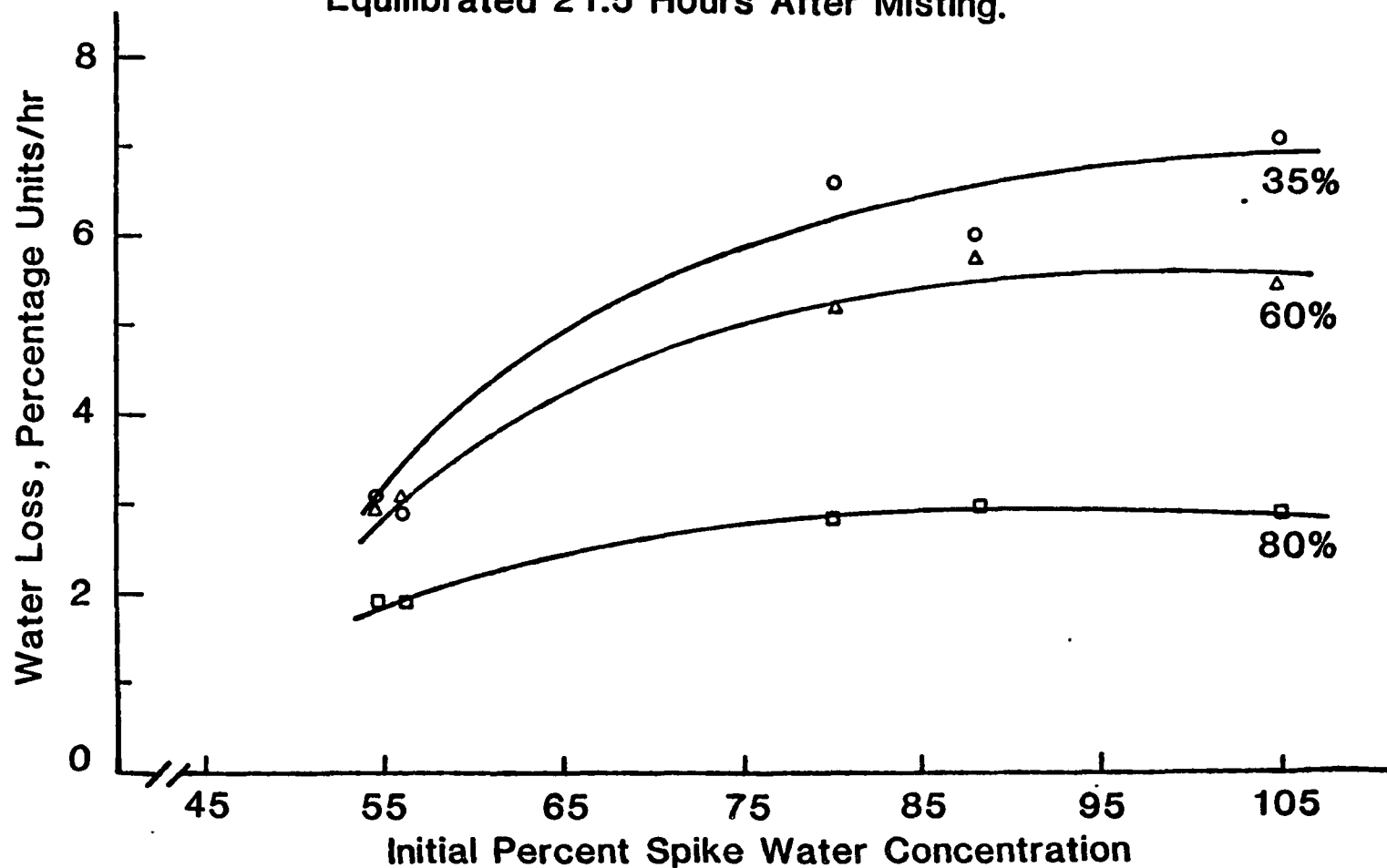
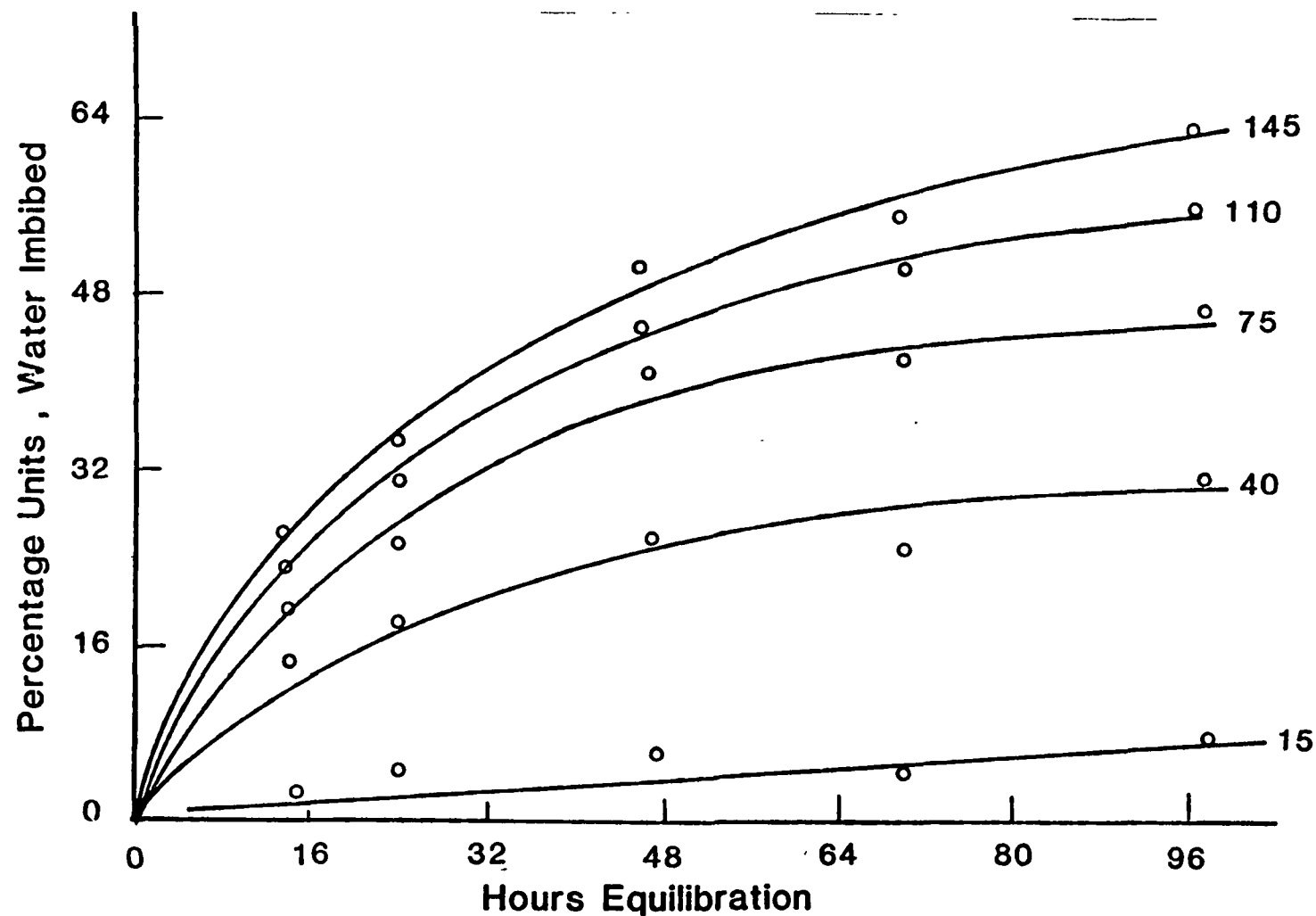


Figure 3. Effect of Relative Humidity on Average Water Loss Per Hour for 8 Hours From 40 Wared Wheat Spikes Equilibrated 21.5 Hours After Misting.



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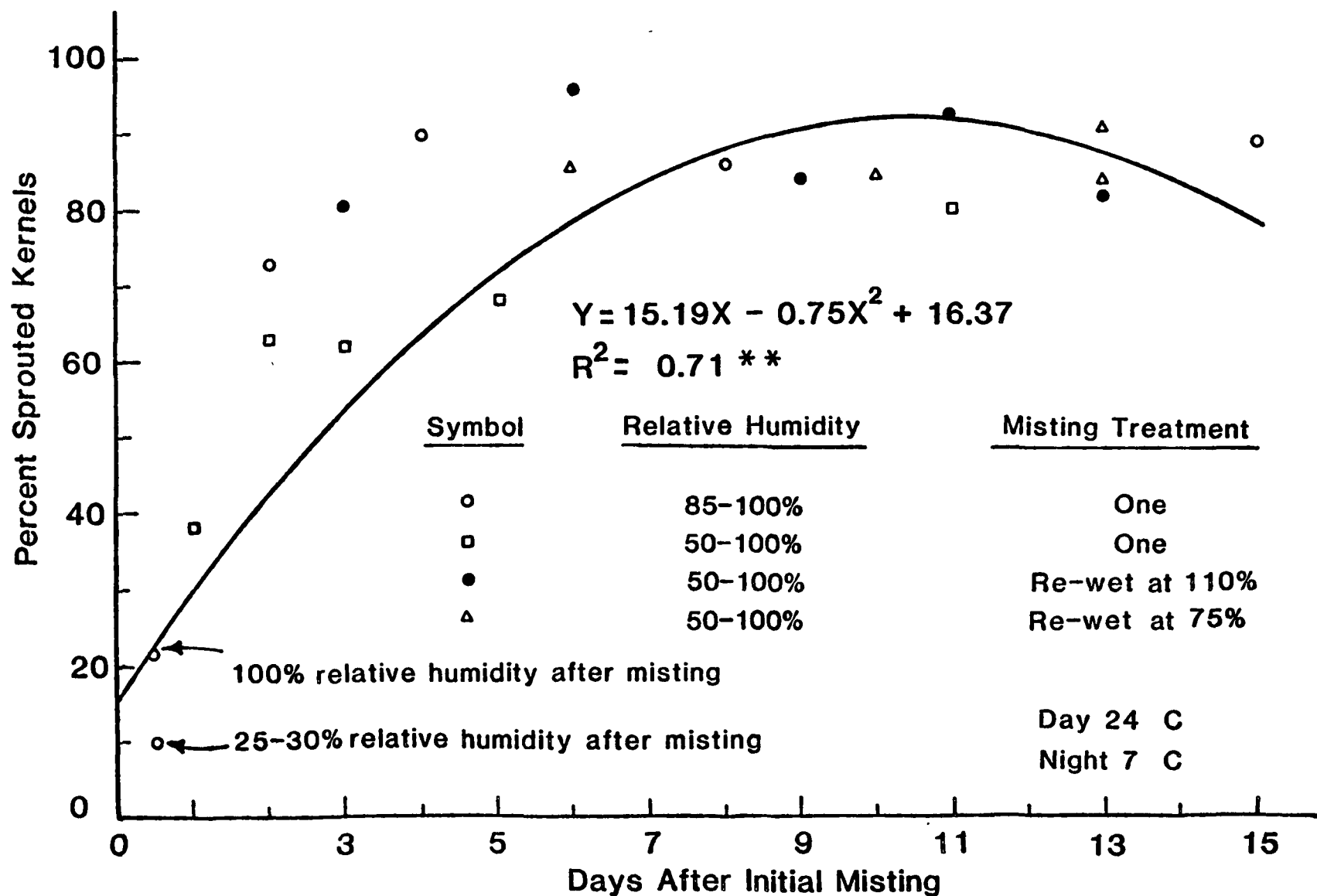
Figure 4. Effect of Equilibration Time on Percentage Units of Water Imbided by Grain, Oven-dry Grain Weight Basis, From Wheat Spikes Misted to Five Water Concentrations.



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<u>% Water</u>	<u>Regression</u>	<u>R²</u>
15	$Y = 0.0612X + 1.7$	$R^2 = 0.65$
40	$Y = 1.153X + 0.0143X^2 + 0.0000006X^4 + 0.0$	$R^2 = 0.99$
75	$Y = 1.514X + 0.0156X^2 + 0.0000005X^4 + 0.2$	$R^2 = 0.996$
110	$Y = 1.791X + 0.0231X^2 + 0.000108X^3 + 0.2$	$R^2 = 0.999$
145	$Y = 2.082X + 0.286X^2 + 0.000143X^3 + 0.02$	$R^2 = 0.999$

Figure 5. Percent Sprouting in 300-Spike Bundles of Wared Wheat Initially Misted 16 Hours to 150% Water Concentration. Some Bundles Were Re-misted When Water Concentration Decreased to 110% and 75%.



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